Trends in Saharan dust and tropical Atlantic climate during 1980–2006

Gregory Foltz

Joint Institute for the Study of the Atmosphere and Ocean (JISAO)
University of Washington, Seattle, WA USA

Michael McPhaden

NOAA/Pacific Marine Environmental Laboratory, Seattle, WA USA

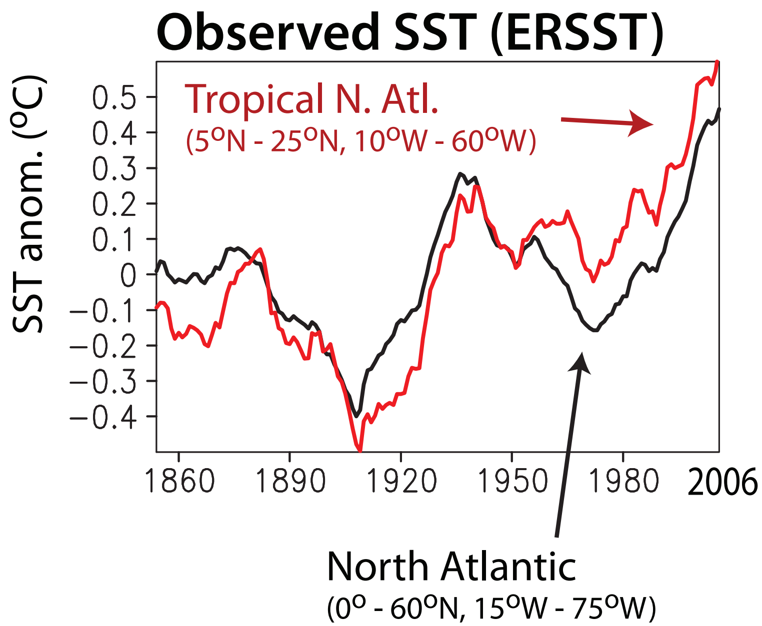
Tropical Atlantic meeting, Toulouse, 3–6 February 2009

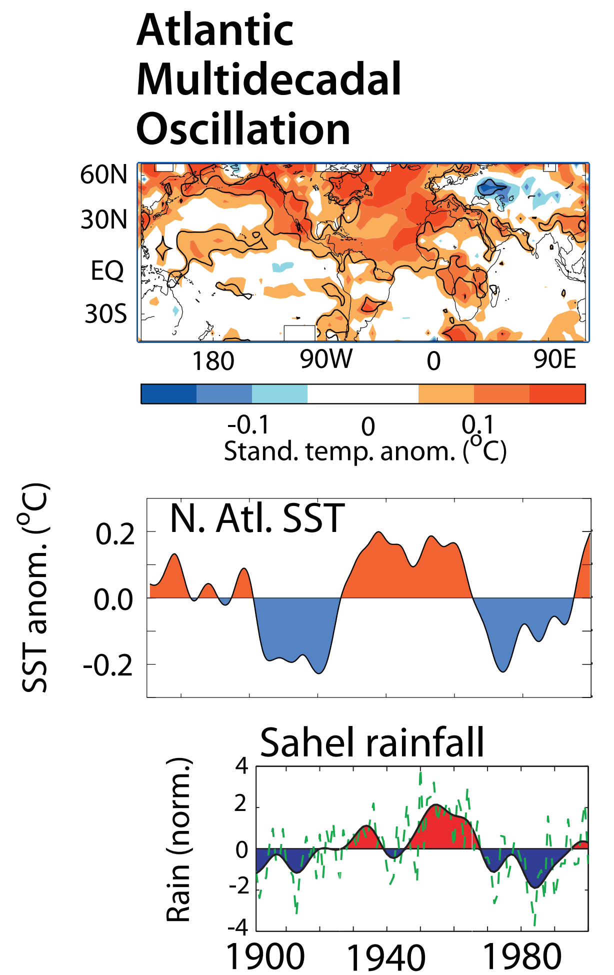
- *Questions*: What are the linear trends in tropical Atlantic **SST**, Sahel **rainfall**, and Saharan **dust** during 1980–2006? What was the impact of dust on tropical North Atlantic SST?

- *Approach*: Analyze satellite and in situ data sets and use simple one-dimensional models.

Foltz, G. R., and M. J. McPhaden, 2008: Trends in Saharan dust and tropical Atlantic climate during 1980–2006, *Geophys. Res. Lett.*, **35**, L20706, doi:10.1029/2008GL035042.

Tropical North Atlantic SST and Sahel rainfall

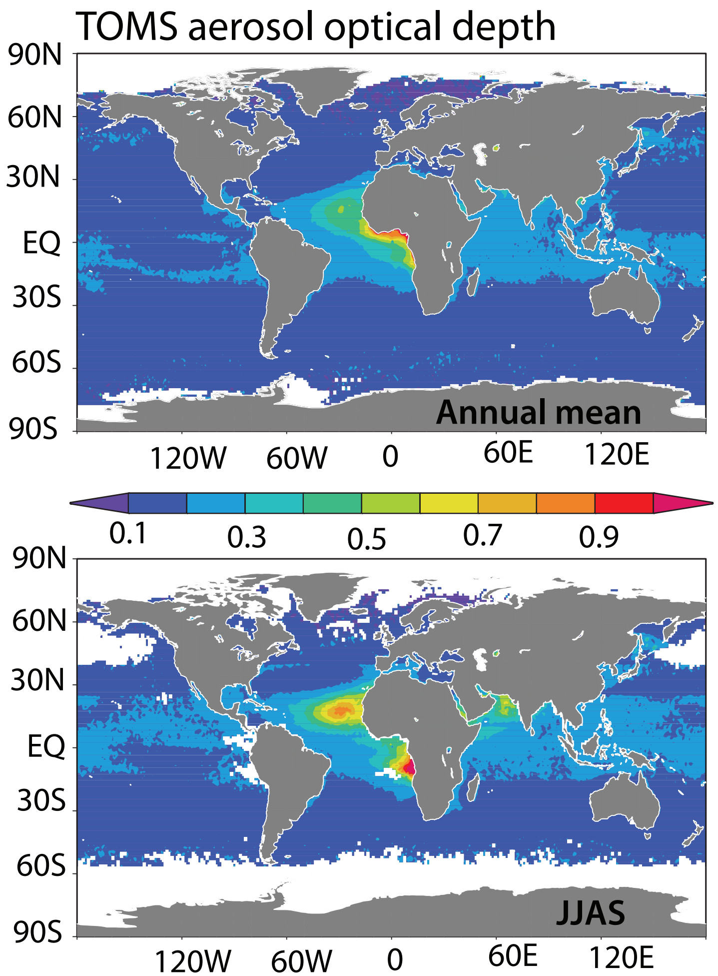




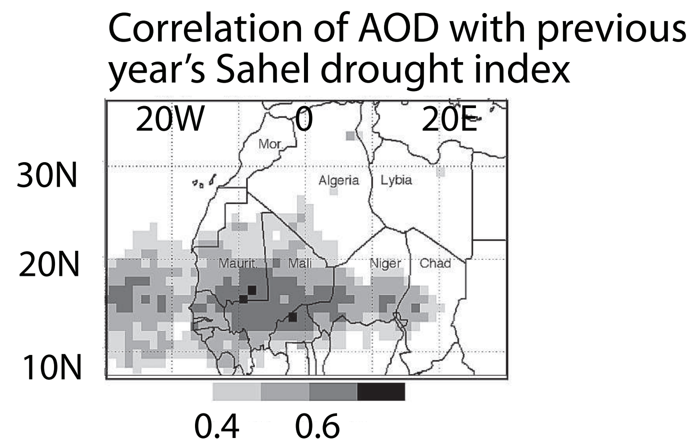
- Multidecadal oscillations of SST linked to AMO and Sahel rainfall

Knight et al. (2005), Zhang and Delworth (2006)

Saharan dust



- High dust conentrations in the tropical N. Atl. during boreal summer.



Moulin and Chiapello (2004)

- NW Sahel controls most of the interannual variability of dust transport to the tropical Atlantic. Rainfall exerts a strong influence on dust production.

Impact of dust on SST

- Dust absorbs and scatters incoming solar radiation, cooling tropical N. Atl. SST by $\sim$0.5°C per month (*Yoshioka et al.*, 2007; *Evan et al.*, 2008)

- Interannual variations of dust concentration have a significant impact on tropical N. Atl. SST, explaining $\sim$30% of summertime SST variance (*Evan et al.*, 2008; *Foltz and McPhaden*, 2008).

Positive feedback loop?

SWR (increase)

N. Atl. SST (increase) → **Sahel rain** (increase) → **Dust** (decrease)

- **Purpose of this study:**

  Investigate **Rain** → **Dust** → **SST** connection during 1980-2006.

Data

- SST: *Reynolds et al.* (2002) for 1981–2006, Extended Reconstructed SST (*Smith et al.*, 2008) for 1980–1981.

- Dust: Aerosol optical depth from TOMS (1980–2001) and MODIS (2002–2006).

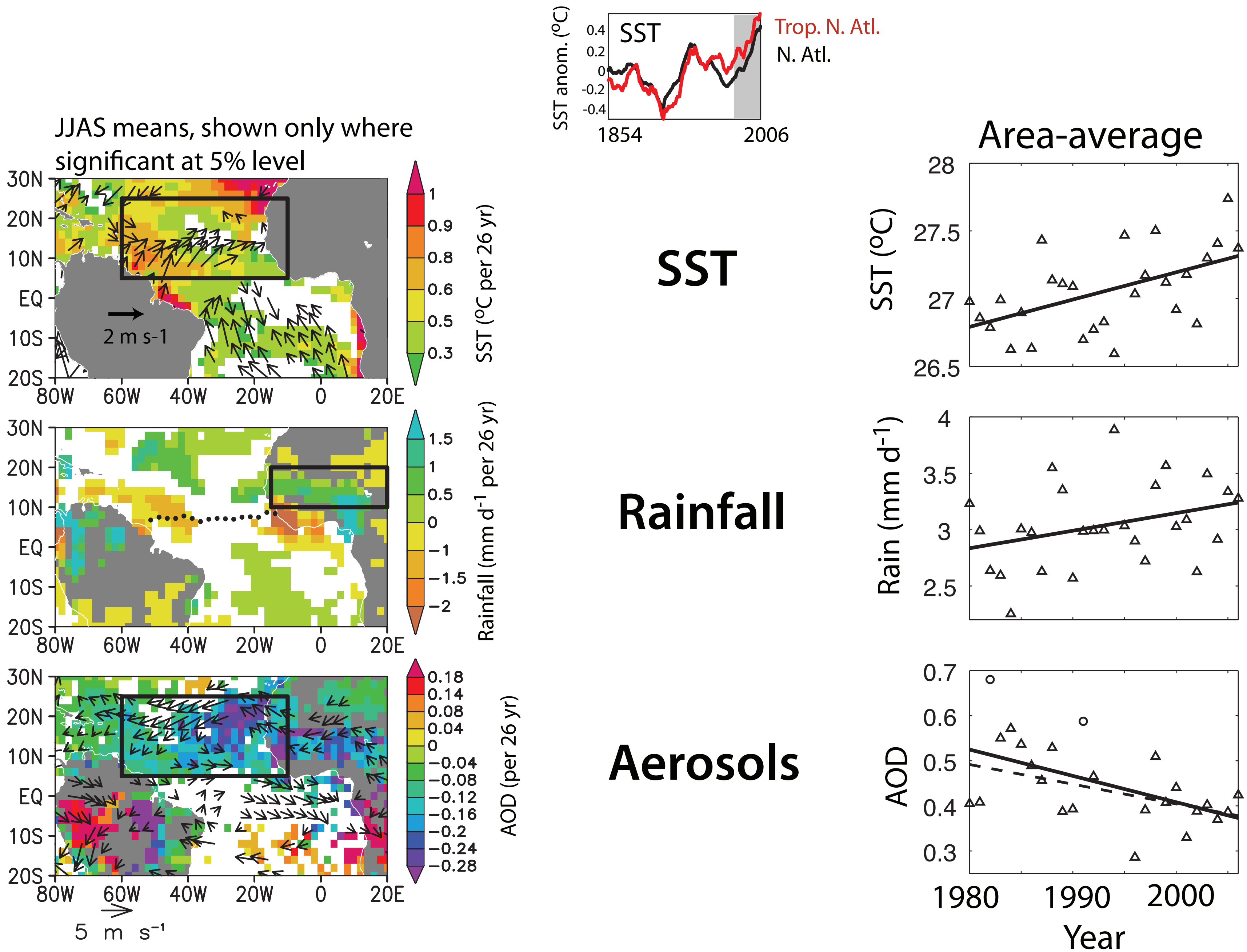
- Rainfall: satellite-in situ blend (CMAP).

- Winds: NCEP reanalysis-2.

Data

- Clouds: ISCCP climatology (1984–2007).
- Mixed layer depth: *de Boyer Montégut et al.* (2007) climatology.

Linear trends (1980 - 2006)



Dust-induced trends in surface radiation

Reduction in surface SWR due to dust

Clear-sky fraction (~0.4)

$$\mathrm{SWR_{dust}} = e_{\mathrm{SWR}}\, f_{\mathrm{CS}}\, A$$

Aerosol optical depth

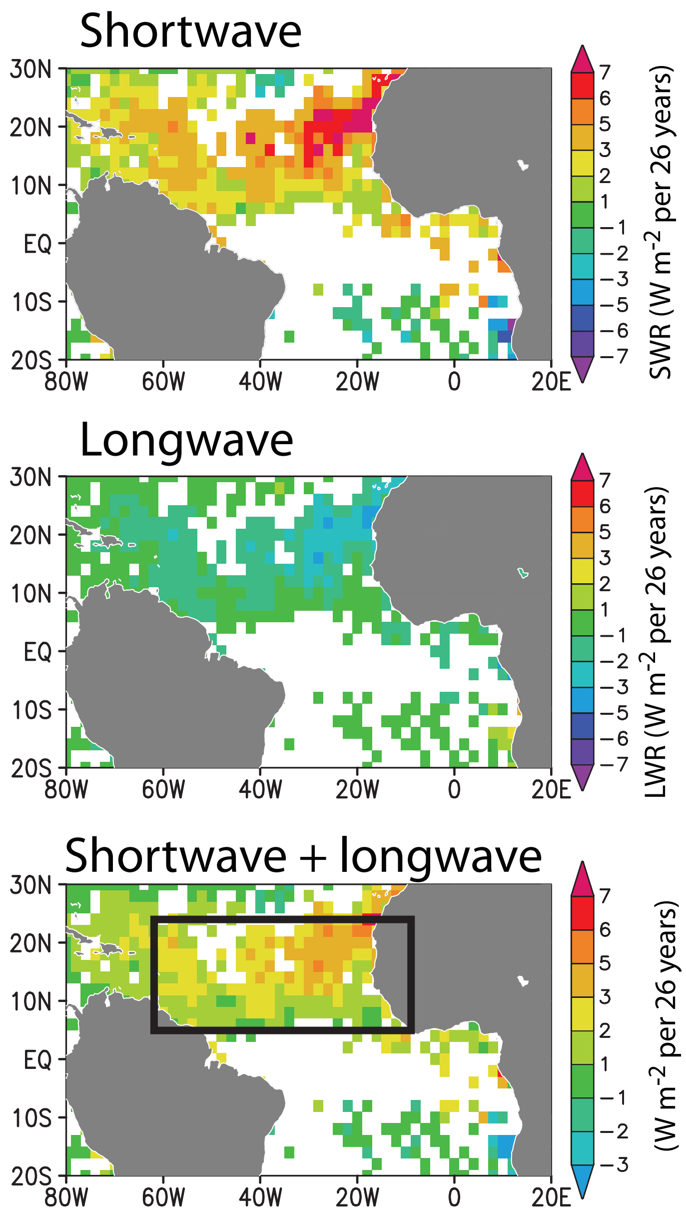
Clear-sky surface SWR forcing efficiency (70 W m^{-2} per AOD; *Zhu et al.*, 2007)

$$\mathrm{LWR_{dust}} = e_{\mathrm{LWR}}\, f_{\mathrm{CS}}\, A$$

Reduction in net LWR emission due to dust

25 W m^{-2} per AOD

Dust-induced trends in radiation



Reduced dust during tended to increase surface shortwave (warming effect) and increase net longwave emission (cooling effect).

Net increase in surface radiative heating of **0.7 W m^{-2}** averaged in tropical N. Atl.

- GHG radiative heating: **1.6 W m^{-2}**
- Radiative cooling due to anthro. aerosols: **0.4 W m^{-2}**

Dust-induced trends in SST

- Integrate simple 1-D mixed layer heat budget
- Does not account for: verical mixing, latent + sensible heat fluxes

Change in SST (2006 minus 1980)

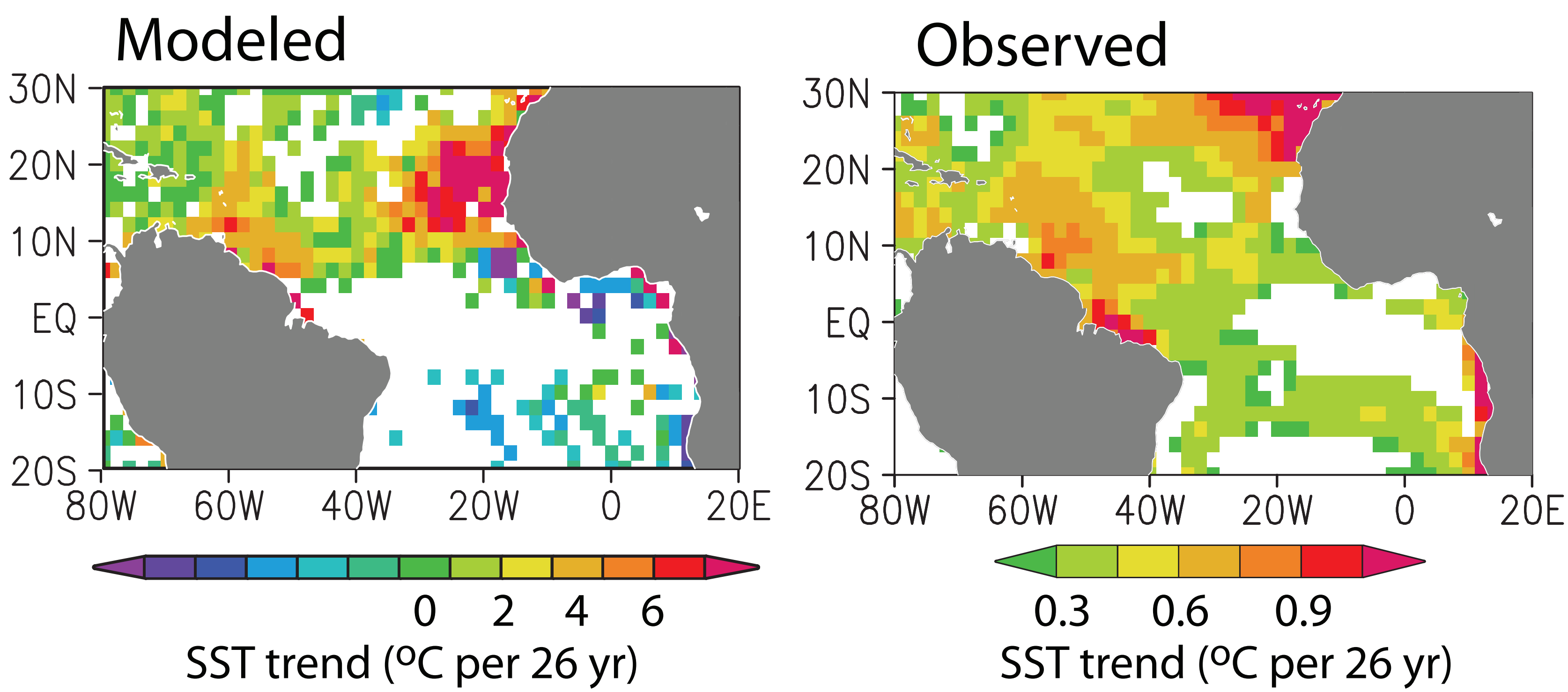
1 month

Mixed layer depth (monthly clim.)

$$\Delta SST = \frac{\Delta t}{\rho c_p} \sum_{i=1}^{324} F_i / h_i$$

Monthly dust-induced surface rad. w.r.t. 1980 value

Dust-induced trends in SST



- Dust-induced increase in tropical N. Atl. SST was **3ºC** during 1980 - 2006, compared to **0.6ºC** actual increase.

- Significant portion of dust-induced heating was balanced by surface turbulent heat loss, vertical mixing, horizontal transport.

Summary

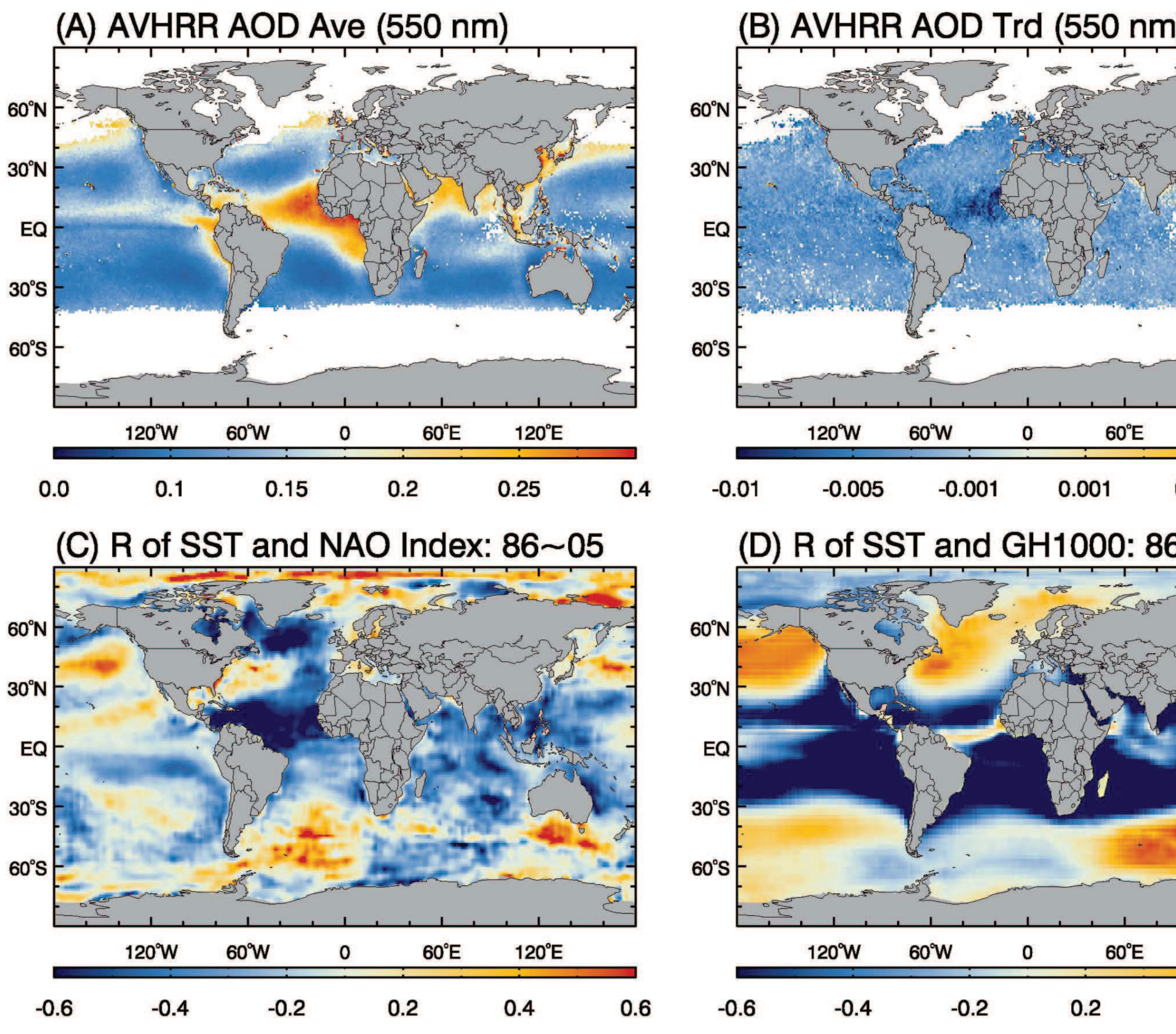
- During 1980–2006 there was a significant increase in tropical N. Atl. SST, an increase in Sahel rainfall, and a decrease in dust concentration.

- Decreased dust loading tended to increase the surface radiative heat flux by 0.7 W m^{-2}, comparable to anthropogenic-induced radiative heating (1.6 W m^{-2}) and cooling due to anthropogenic aerosols (0.4 W m^{-2}).

- Based on a simple 1-D model, the dust-induced increase in radiative heat flux would have increased tropical N. Atl. SST by 3°C, suggesting that other processes were important in redistributing the heat (horiz. advection, vert. mixing, latent + sensible heat flux).

Questions

- Contribution of dust to observed North Atlantic warming and AMO?
- Impact of dust on biological productivity in the tropical N. Atl.?
- Importance of coupled ocean-atmosphere-land feedbacks?


(A) AVHRR AOD Ave (550 nm)
60°N
30°N
EQ
30°S
60°S
120°W
60°W
0
60°E
120°E
0.0
0.1
0.15
0.2
0.25
0.4
(B) AVHRR AOD Trd (550 nm
-0.01
-0.005
-0.001
0.001
(C) R of SST and NAO Index: 86~05
-0.6
-0.4
-0.2
0.2
0.4
0.6
(D) R of SST and GH1000: 86